Study on the double-planed shallow seismic zone in the northeast Japan forearc region

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Abstract

Knowledge of the accurate locations of earthquakes and their focal mechanisms in subduction zones constitutes important information in terms of gaining a better understanding of the subduction process of oceanic plates beneath continental plates. Some of the difficulties encountered in determining focal depths for offshore shallow earthquakes using regional seismic network arrival times recorded at onland stations arise from a lack of seismic network detectability and the inadequate distribution of seismic stations. Hypocenters of suboceanic earthquakes are typically mislocated when using conventional location methods based on a simple one-dimensional seismic velocity structure model. Since it is not so easy to carry out long-term Ocean Bottom Seismograph observations, effective method is required for better determination of hypocenters, especially focal depths, of offshore events. Focal depths can be determined accurately even for earthquakes that occur outside an observation network, provided that depth phases from the events can be detected. Umino et al. (1995) revealed that distinct sP phase: an upgoing S-wave from the focus that is then reflected and converted to a P-wave at the Earth's surface before diving into the Earth again finally arriving at seismic stations, can be observed from offshore shallow earthquakes in the NE Japan forearc region.

In the present study, we detected the sP depth phase at small epicentral distances of about 150 km or more in seismograms of shallow earthquakes in the NE Japan forearc region. Waveform data investigated are those observed at the Tohoku University network, networks of Japanese university group, Japan Meteorological Agency (JMA) network and Hi-net. Focal depths of 1078 M>3 earthquakes that occurred from 2000-2006 were precisely determined using the time delay of the sP phase from the initial P-wave arrival. Distinct sP depth phase can be observed from ~35% of offshore shallow earthquakes. Only earthquakes with distinct sP depth phase recorded at three or more stations were selected, and their focal depths were estimated from the sP-P delay recorded at each station. By calculating the average of focal depths estimated from sP-P times at individual stations, we determined the focal depth of each earthquake. Scatter in focal depths estimated from sP-P times at individual station is about 5 km. Then, origin times and epicenters of those earthquakes are re-determined by assuming focal depths estimated from sP depth phase. About 90% of earthquakes have been relocated within 15 km distance from their original epicenters. The distribution of relocated hypocenters clearly shows the configuration of a double-planed shallow seismic zone beneath the Pacific Ocean. The upper plane has a low dip angle near the Japan Trench, increasing gradually to ~30° at approximately 100 km landward of the Japan Trench. The lower plane is approximately parallel to the upper plane, and appears to

be the near-trench counterpart of the lower plane of the double-planed deep seismic zone beneath the land area. The distance between the upper and lower planes is 28-32 km, which is approximately the same as or slightly smaller than that of the double-planed deep seismic zone beneath the land area.

We found that seismograms of earthquakes in the upper and lower planes of the double-planed shallow seismic zone in the NE Japan forearc region show remarkable differences: Seismograms for upper plane events display

(1) indistinct direct P- and S- waves,

(2) many later phases following direct P- and S-waves, and

(3) a predominance of comparatively low frequency in seismogram.

In contrast, seismograms observed from lower plane events clearly show

(1) distinct direct P- and S- waves,

(2) virtually no later phases, and

(3) a predominance of comparatively high frequency components.

Out of the three notable contrasting waveform features of upper and lower plane events, the presence of significant later phases is evaluated quantitatively in this study. We compare the maximum amplitudes of direct P- and S-waves with the average amplitude of coda waves. Waveforms of earthquakes that have no distinct sP depth phase can be roughly categorized into two groups on the basis of the amplitude ratio of direct waves to later phases, and there is no case in which a waveform cannot be categorized on this basis. This suggests that approximately 65% of all earthquakes, those with no distinct sP depth phase, can be categorized into two groups; those with a focal depth at a depth of around 10 km, and those occurring at a depth of around 40 km. This also seems to confirm the existence of a double-planed shallow seismic zone.

Focal mechanism solutions of the relocated earthquakes are determined from P-wave initial motion data obtained by the Tohoku University network, JMA network and Hi-net. Although P-wave initial motion data for these offshore events are not ideally distributed on the focal sphere, we found that upper-plane events that occur near the Japan Trench are characterized by normal faulting, whereas lower-plane events are characterized by thrust faulting. This focal mechanism distribution is the opposite to that of the double-planed deep seismic zone beneath the land area (Umino & Hasegawa, 1975; Hasegawa et al., 1978a). The characteristics of these focal mechanisms for the shallow and deep doubled-planed seismic zones can be explained by a bending-unbending model of the subducting Pacific plate (Isacks & Barazangi, 1977; Engdahl & Scholz, 1977). Some of relocated earthquakes took place in the source area of the 1933 Mw8.4 Sanriku earthquake at depths of 10 to 23 km. The available focal mechanisms for these events are characterized by normal faulting. Given that the 1933 event was a large normal-fault event that occurred along a fault plane dipping landward (Kanamori, 1971), the earthquakes that currently occur just beneath or oceanward of the Japan Trench are probably its aftershocks, suggesting that aftershock activity continues to the present day, 70 years after the main shock.

In conclusion, the double-planed seismic zone can be confirmed even in the NE Japan forearc region, and focal mechanism pattern of the double-planed shallow seismic zone is quite opposite to that of the double-planed deep seismic zone beneath the land area. The bending and unbending process might be one of plausible models causing this earthquake generating stress field within the Pacific plate.

論文審査の結果の要旨

本論文は，東北日本前弧域における二重浅発地震面を，世界で初めて見いだしたものである。

地震観測網の外側で発生する地震の震源位置，特に，震源の深さを正確に決定することは，一般には困難である。本論文では，東北日本太平洋下で発生した地震のうち，震央距離が約 150~300 km の地震記録に現れることがある sP 波（震源から出たＳ波が地表でＰ波に変換して反射し，観測点に到達する地震波）を用いて，それらの地震の震源の深さを正確に決定することを試みた。得られた震源の深さ分布は約 10 km と約 40 km の二つのグループに大別され，日本海溝から東北日本太平洋沿岸にかけてほぼ平行に分布している。すなわち，それらの地震活動は，東北日本内陸下に見られる二重深発地震面とほぼ同様な傾向をもつ，二重浅発地震面を形成していることが明らかとなった。

本論文では，上面と下面の地震の記録波形に顕著な相違があることを指摘した。下面の記録はＰおよびＳ波が顕著であり，高周波成分に富んでいる。一方，上面の記録には，多数の後続波が見られ，卓越周波数は低周波である。これらの波形の特徴は震源から観測点までの波線の違いによるものであると考察している。波形の特徴を基にして震源の深さを推定する手法を提案し，すべての地震の深さを区別することを試みた。その結果，多数の浅い地震が認識され，それらの地震は上面の地震の分布と良く一致していることが明らかとなった。深い地震の活動は下面の地震と同様に低調である。

Ｐ波初動分布からメカニズム解を求めた結果，上面の地震は正断層型で，下面の地震は逆断層型であることがわかった。このメカニズム解分布は，二重深発地震面のそれとは正反対である。これらのメカニズム解分布から，太平洋プレート内部の起震応力場を説明するために，プレートの bending-unbending model を提唱した。また，1933 年三陸地震（Mw 8.4）の震源域では，現在でも正断層の地震が深さ 23 km 付近まで発生しており，70 年を経過しても余震活動が継続している可能性を指摘した。

以上のように，N. G. S. Shantha 提出の論文は，初めて二重浅発地震面を見いだし，メカニズム解分布を明らかにし，モデルを提出することにより，プレートの沈み込み過程を理解する上で新知見をもたらした。これは同人が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。よって N. G. S. Shantha 提出の論文は，博士（理学）の学位論文として合格と認める。